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Discussion: Evaluation of strength and stiffness response of coir-fibre-reinforced soil

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1. INTRODUCTION

The authors have presented a simple method to quantify the degree of improvement obtained by reinforcing sand with randomly distributed coir fibres, in terms of the strength and stiffness of the coir-fibre-reinforced soil. Further, the analytical models available in the literature for obtaining the degree of improvement due to synthetic fibres have been examined with respect to experimental data on coir-fibre-reinforced soil samples. The technique of soil improvement using coir fibres and products has several advantages.

(*a*) As stated by the authors, 'The ability of the natural fibres to absorb water and degrade with time are the principal properties that give them an edge over synthetic materials.'
(*b*) In countries where the availability and cost of synthetic and metallic reinforcing materials are major constraints, reinforced soil systems using natural materials such as coir have tremendous application potential.
(*c*) Coir is reputed to be among the strongest and most durable of all natural materials. Because of coir's high lignin content, it degrades much more slowly than other natural materials in an earth context.[1,2]

These advantages make any in-depth research on coir worthwhile.

The authors have conducted triaxial tests on sand reinforced with coir fibres to study the effect of coir as a random reinforcing material. The discussers have also carried out experimental studies to investigate the potential of coir as a soil-reinforcing material.[3] This study examines the undrained response of clay samples reinforced with sand–coir fibre cores in triaxial tests. An attempt was made in this study to identify and isolate the influence on the behaviour of reinforced soil samples of variables such as replacement area ratio (ratio of cross-sectional area of sand–coir fibre core to that of the triaxial test sample), confining pressure, fibre content, and fibre aspect ratio (length-to-diameter ratio of fibres). Based on the discussers' experiences and observations, this note aims to discuss some features of the coir-fibre-reinforced soil as presented by the authors. In particular, a critical comparison of the observations made by the authors and the discussers regarding the influence of some variables on the behaviour of the reinforced soil sample is presented.

2. FIBRE CONTENT

The stress–strain response of sand reinforced with coir fibres (Figure 2) shows an increase in the initial stiffness as well as the deviator stress at failure with increasing fibre content, for confining pressures of 100 kPa and 150 kPa. A fibre content up to 1·5% (by weight) was used by the authors in their experiments. The discussers also have observed that the initial stiffness and maximum deviator stress of the composite sample depend on fibre content. However, the optimum value of fibre content – the value that yields the best result as far as soil improvement is concerned – was found to be about 1% by weight. Six fibre contents (0%, 0·5%, 1%, 1·5%, 2% and 3%) were used in this study. It was observed that at higher fibre contents the relative volume occupied by the coir fibres in the sand–coir fibre core becomes so large that fibre–fibre interaction dominates rather than sand–fibre interaction, resulting in a reduced degree of improvement compared with that at 1% fibre content. The optimum fibre content may probably be a function of several variables, including the gradation and relative density of the sand, the type of coir fibre, and the interaction coefficient between the sand and the coir fibre. Further, the discussers tested soft clay samples reinforced with a central core of a sand–coir fibre mixture, whereas the authors' studies were on sand samples reinforced with randomly oriented coir fibres. These factors also might be reasons why different results were obtained for the influence of fibre content. However, the discussers feel that Equation 6 should be used with caution, since it yields only increasing values of stiffness modulus with increasing fibre content, and no reverse trend is predicted, whatever the properties of fibres and sand used.

3. FIBRE ASPECT RATIO

The length and diameter of the fibres used by the authors in all their experiments were 15 mm and 0·25 mm respectively. All the tested samples thus had an aspect ratio (length-to-diameter ratio) of 60. Coir fibres with fibre aspect ratios of 60, 83·3 and 100 were used by the discussers in their experiments. This study indicated that the aspect ratio of the fibre has relatively less influence on soil improvement than other parameters. The increase in maximum deviator stress for a change in aspect ratio from 60 to 100 lies in the range 14–26% for different combinations of the variables considered in this study. The influence of aspect ratio on maximum deviator stress was found to be practically the same at all confining pressures, whereas it was found to decrease with an increase in replacement area ratio. Further, the influence of aspect ratio was minimal near the optimum fibre content.

4. CONFINING PRESSURE

Comparison of Figures 2a and 2b shows that both the initial stiffness and the maximum deviator stress for a confining pressure of 150 kPa are higher than for a confining pressure of 100 kPa (all other parameters being the same). This is also evident from the data presented in Tables 2 and 3. The discussers' study[3] indicates similar trends. However, the beneficial effect of soil reinforcement (defined by the ratio of the maximum deviator stress of the reinforced soil to that of the unreinforced soil) was found to increase with increase in confining pressure, whereas a reverse trend is predicted by the authors. For example, for an increase in fibre content from 0% to 1% (Table 2), the maximum deviator stress was found by the authors to increase from 450 kPa to 847 kPa (a factor of 1·88) at a confining pressure of 100 kPa, while at a confining pressure of 150 kPa the corresponding variation was from 669 kPa to 886 kPa (1·32 increase). In contrast, the discussers observed these values to be 148 kPa and 212 kPa at a confining pressure of 100 kPa (1·43 increase) and178 kPa and 286 kPa at a confining pressure of 150 kPa (1·61 increase), for a fibre aspect ratio of 60 and a replacement area ratio of 0·28. The improved response shown by the reinforced soil samples at higher confining pressures is probably due to localised drainage occurring in the central core. Coir is quite hygroscopic in nature, with a moisture absorption of about 10–12% at 65% relative humidity. The discussers are of the opinion that the hygroscopic nature of coir fibres, and the possibility of increased frictional interaction between sand and coir fibres that may occur at higher confining pressures, would probably result in an improved response at higher confining pressures. An improvement in the response of test samples at higher confining pressures would make the use of the coir fibre reinforcement technique preferable for stabilisation of deeply buried soil deposits, whereas a reduced improvement at higher confining pressures would suggest that the technique is more suitable for shallow deposits. This merits more detailed study.

The work presented by the authors adds greatly to the development of research in the area of coir fibres and products. It provides a good basis for the potential use of coir fibres in field applications. By conducting more in-depth studies, equations, charts and nomographs for practical use can be developed.

Authors' reply

The authors thank the discussers for their comments. As indicated in the discussion, they observed a similar improvement in soil properties due to the addition of coir fibres. However, there are certain points of difference from the views of the discussers, which are described below.

1. SOIL USED IN THE STUDY

The authors conducted the experiments with dry sand reinforced with coir fibres randomly distributed throughout the specimen (38 mm diameter and 76 mm high specimen), whereas the discussers' experiments used clay specimens with a central sand–coir fibre core (a larger specimen), which is similar to a fibre-reinforced sand column. Hence the mechanism of strength improvement may not be completely similar in the two cases.

2. OPTIMUM FIBRE CONTENT

The authors carried out their tests with dry sand for 0·5%, 1·0% and 1·5% coir fibre content, which showed that the peak deviator stress increased as the fibre content increased. No optimum fibre content for maximum improvement was observed. The peak deviator stress increases marginally even at 2·5% fibre content, and this was also observed in another set of experiments with a red soil–coir fibre mixture.

3. LENGTH OF FIBRES

The length of fibres, compared with the specimen size, influences strength improvement. For a given fibre content, if the fibre length is greater, the number of fibres is smaller, and vice versa. As a result, the interaction between fibre and soil or fibre and fibre may dominate, depending on the fibre content. There is an optimum length, which depends on the specimen size.

4. ASPECT RATIO

All the fibres used in the study have the same length and diameter, and hence the aspect ratio is the same for all specimens. It is likely that the aspect ratio has minor significance. The results of triaxial compression tests using red soil reinforced with coir fibres having various parameters indicate the following. One set of tests used fibres 15 mm long with an average diameter 0·35 mm and aspect ratio of 43. In another set of tests, the fibres were again 15 mm long, but the average diameter was 0·15 mm and the aspect ratio was 100. The improvement in strength over plain soil was observed to be greater for the former case, in which the aspect ratio was less.

The aspect ratio may be a factor for synthetic fibres, since the tensile strength of small-diameter fibres is likely to be greater. This is because synthetic fibres are stretched during the manufacturing process, resulting in the rearrangement of molecules in an orderly manner. However, such processes are not used in the case of natural fibres.

5. CONFINING PRESSURE EFFECT

The effect of confining pressure on strength improvement depends mainly on the relative density, initial void ratio, gradation and condition of sand. As indicated earlier, there is a difference in the experiments of the discussers from that of the authors, and the confining pressure effects need detailed study in both cases using appropriate analysis methods. The equation for the stiffness of coir-fibre-reinforced soil, based on the experimental results with sand, can be used up to a fibre content of 1·5%, and is not based on a general approach. Additional research is necessary in this direction.

The discussers must be complimented for bringing out some important points that are required in the study of fibre-reinforced soils, and such detailed studies on the use of natural fibres in ground improvement are desirable.

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